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Systems analysis – a new paradigm and decision support tools for the water framework directive

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Abstract

In the early days of Systems Analysis the focus was on providing tools for optimisation, modelling and simulation for use by experts. Now there is a recognition of the need to develop and disseminate tools to assist in making decisions, negotiating compromises and communicating preferences that can easily be used by stakeholders without the need for specialist training. The Water Framework Directive (WFD) requires public participation and thus provides a strong incentive for progress in this direction. This paper places the new paradigm in the context of the classical one and discusses some of the new approaches which can be used in the implementation of the WFD. These include multi-criteria decision support methods suitable for environmental problems, adaptive management, cognitive mapping, social learning and cooperative design and group decision-making. Concordance methods (such as ELECTRE) and the Analytical Hierarchy Process (AHP) are identified as multi-criteria methods that can be readily integrated into Decision Support Systems (DSS) that deal with complex environmental issues with very many criteria, some of which are qualitative. The expanding use of the new paradigm provides an opportunity to observe and learn from the interaction of stakeholders with the new technology and to assess its effectiveness. This is best done by trained sociologists fully integrated into the processes. The WINCOMS research project is an example applied to the implementation of the WFD in Ireland.

1 Introduction

The EU Water Framework Directive (WFD) requires that every country introduce measures to improve and sustainably maintain good chemical water quality status by 2015. Regardless of any scientific and economic justification, it is unlikely that all proposed measures or policies will be acceptable to all stakeholders so that considerable controversy and some planning and legal challenges can be expected. Consultation, negotiation, compromise and refinement of measures can be expected. Thus it is imperative

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that all decisions on policy and measures be taken not only (i) on the basis of the best available scientific and economic information but also (ii) be taken using an unbiased, independent and logical methodology and (iii) take account of all stakeholders concerns, both quantifiable and non-quantifiable, in a transparent manner. This requires the "systems approach" to decision making. Given the complexity of the scientific processes and computer models involved, a computer-based decision support system with multi-criteria analysis capability is an essential tool in such a decision-making chain. It must have access to the best information on available measures and it must be able to interact with stakeholders (two way communication) to reliably gauge their opinions and preferences and to incorporate them in the decision analyses. This paper starts with a description (in Sects. 2 and 3) of how the classical systems approach to decision making in relation to large infrastructural projects has, in practice, expanded to include feedback loops involving negotiation, compromise and possibly revision of priorities. Then, in Sect. 4, some new analysis tools and methods are described which support the new paradigm. Finally, Sect. 5 describes briefly some examples of the new types of decision support systems which have emerged to facilitate the use of these new methods by all types of stakeholder.

2 Systems approach – the classical paradigm

De Neufville (1990) defined systems analysis as "the use of rigorous methods to help determine preferred plans and designs for complex, often large-scale systems. It combines knowledge of the available analytic tools, understanding of when each is more appropriate, and skill in applying them to practical problems. It is both mathematical and intuitive as is all planning and design." Ossenbrugger (1984) defined it as "a coordinated set of procedures that can be used to address issues of project planning, engineering design and management. Systems Analysis is a decision making tool. An engineer can use it for determining how resources can be used most efficiently and most effectively to achieve a specified goal or objective." Burus (1972) declared it to be “an extension of the scientific method and it introduces into it a certain degree of formalism, which channels the thinking and guides it through the maze stretched between formulation of objectives and performance of the design”.

All of these definitions focus on the toolbox aspect of the discipline, the collection of appropriate mathematical and numerical tools for solving practical problems, that came to be classified as “hard” systems. Major issues relating to uncertainties in the objectives and criteria and how to deal with multiple decision makers (or stakeholders) with competing objectives did not arise at that stage. A fixed and knowable set of objectives was assumed although it was recognised that some effort may be needed to confidently generate the complete set. A rational and unwavering decision maker was also usually assumed.

When systems analysis was applied to water resources projects and river basin management, the projects often related to very large scale measures, involving significant infrastructural, policy or legislative changes, and it was considered desirable to formalise the various activities involved in making decisions about the design and/or management of such measures. The classical paradigm for such a systematic approach to decision making contains the following five steps:

(i) *Definition of objectives*

The objectives of the project are specified. For a commercial project, the “client’s” objectives are paramount, maximise profit or shareholders’ value in a Public Company. However, in the context of European Directives (and not just the WFD), the issue is more complex. It would be too easy to say it is the “stakeholders” objectives which *should* count. However, the WFD envisages stakeholders having an advisory role and it is typically a government department or organisation which implements and pays for the WFD measures so that their objectives are important and must be considered. A complicating factor is that large-scale water resources problems usually involve a wide range of objectives and have a wide range of significant benefits and impacts and corresponding assessment criteria. While many of the objectives will map to specific objectives of the WFD, there will be others, such as "equity", "national or regional development" which are obvious concerns for the implementing authorities.

(ii) *Establish measures of effectiveness*

Procedures must be established for assessing each objective or criteria. They may be quantitative (e.g. cost) or qualitative (e.g. visual impact, taste etc.). In most cases there are many different ways to assess any one objective. For instance for any physical quantity a criterion could be a long term average, a mean daily average (or over any period) or the number or duration of exceedences of a threshold. The choice of measure can unintentionally bias the decision making process. The assessment may be qualitative or quantitative.

(iii) *Generation of alternatives*

A list of possible types of solution is generated. In the context of the WFD these are the "measures". The list should be as complete as possible and cover all the possible categories of measures. Typically the more people contribute to the discussion the longer the list. Lateral thinking (de Bono, 1967) is desirable and good results are possible from managed group interactions, such as with Metaplan (http://www.metaplan.com), brain-storming or similar systems.

(iv) *Evaluation of alternatives*

All of the possible types of solution are evaluated in relation to the measures of effectiveness for each criterion. This invariably requires modelling and simulation which produces an assessment matrix with an assessment for each criteria for each alternative (measure).

(v) *Decision or recommendation*

The results of the evaluation are analysed and decisions or recommendations are formulated. When there are many objectives/criteria this may require some trade-off between objectives and multi-criteria decision support techniques can help here.

This classical paradigm, illustrated in Fig. 1 is a linear procedure. The final two steps depend on the results of the three preceding ones so the steps must be completed in the order indicated.

3 A new paradigm

This classical paradigm is valid today in certain circumstances, but does have some fundamental limitations, particularly when applied to complex problems with many important environmental considerations, as with the WFD. This is because the approach assumes that the decision maker(s) are readily identifiable and that their priorities can be readily obtained at the beginning of the analysis and that they do not change over appreciable time scales. This may be true in many circumstances, for instance for most private companies and for some public agencies. However, many decisions relating to large-scale activities or measures related to the WFD have significant environmental impacts and the objectives and priorities of, and impacts on, the general public may not be easy to obtain in the "abstract" initial stages of the analysis. Many people are better able to appreciate the issues and articulate their opinions when faced with a single design proposal to consider. Moreover, priorities and opinions may change over the time-scales envisaged for the implementation of the WFD. Thus the steps shown in Fig. 2 better represent what happens in practise. It is an iterative one in which some feedback from stakeholders is possible after a preliminary "solution" has been proposed. This feedback may lead to a revision of priorities, or to additional alternatives (measures), typically compromises between or combinations of the original ones. The learning process involved may even lead to some refinement of the objectives. The ultimate aim is to find an acceptable compromise between the various, invariably competing, objectives, and this involves negotiation, compromise and perhaps even some rethinking of the project objectives. This was recognised at a comparatively early stage, e.g. by Jamieson (1986) who wrote "River basin management can be characterised as an exercise in conflict resolution". More recently, Wilson and Droste (2000) describe the changing role of analysis and negotiation in environmental decision-making. They identify the need for a new look at the information technology requirements of decision support in the area of water resources. They stress that integration of key management functions should be linked to the Decision Support System (DSS).

4 New tools for the new paradigm

4.1 Multi-criteria methods

4.1.1 Multi-Attribute Utility Methods (MAUT)

Utility represents a person or group's level of satisfaction with a particular outcome and can be used to indicate preference or indifference between the outcomes or consequences of any policy. Its use requires some strong assumptions about the nature of the decision-maker's preference structure and is expressed on an ordered metric scale. The numbers of this scale have no absolute physical meaning and the scale is constructed by assigning arbitrary numbers to any two points. Typically these points correspond to the best (utility = 1) and worst (utility = 0) possible outcomes.

In many cases the decision problems facing engineers and planners involve a large number of different types of criteria. In particular, decisions based on Environmental Impact Assessments may involve a very large number of types of consequences relating to water, air, noise, amenity, landscape, flora, fauna etc. In principle the same utility theory developed for the single decision attribute can be directly extended to cover such cases. Multi-Attribute Utility Theory (MAUT) (Keeney and Raiffa, 1993) generalises the concept of utility to any number of criteria and allows possible consequences to be “traded off” against one another, while also taking account of their probabilities of occurring. The closely related ideas of value and utility have a long history, starting in the field of economics, but are now used in a wide variety of decision-making contexts. For instance, engineers and planners use them when considering alternatives for large-scale projects; especially those related to infrastructure development. Economists use them when analysing the operation of enterprises, markets and economies and especially in the field of welfare economics. Psychologists and social scientists use them in the study of peoples' behaviour and the reasons for the choices they make. The aim is to improve understanding of peoples' preferences and to develop tools to assist in choosing policies which are consistent with these preferences. It is tacitly assumed that such decisions are good ones and that they will be accepted by a large number of the people affected by them.

MAUT as a direct extension of Utility Theory

In principle the multi-attribute utility function can be measured by a direct extension of the way it is done for a single attribute utility function. The utility for two arbitrary reference points is defined and the utility for all other points can be estimated in relation to these. For N criteria, the amount of information required to define the utility function increases in proportion to the power of N, and the amount of data required becomes prohibitive, even for relatively small numbers of criteria and especially for decisions with large numbers of environmental impacts.

For example, suppose that 5 points could adequately represent the utility function for a single criterion. If there were two criteria then the utility function would be a two dimensional function and 5^2–2 or 25 points less the 2 fixed points would be required to represent the utility function with a corresponding level of accuracy. If there are three attributes then 5^3–2 or 123 points are required to represent the function with the same resolution. It is easily seen that the latter would require extensive surveys and interviews making it prohibitively expensive. Even the two dimensional case requires considerable effort if tackled in the direct way. Fortunately this is not required and methods of constructing a multiattribute utility function without such extensive comparisons have been devised (Keeney and Raiffa, 1993).

Weighted average

In the simplest approach, if the utilities of each criterion are independent of the others then the multiattribute utility function is constructed as a weighted average of the utility functions for each individual attribute (consequence), i.e.

$$U(X) = \sum_{\text{all } i} w_i u_i(x_i) \tag{1}$$

where, X = (x_1, x_2, ..., x_n) is an n-element vector of criteria values, U(X) is the multivariate utility function and $u_i(x_i)$ is the univariate utility function for the ith. criterion. The w_i are weights which specify the relative contribution of each criterion in the final decision. They are assumed to be fixed regardless of the magnitude of the criterion value and also are independent of the other criteria. This neglects any cross influences on the degree of satisfaction with any criterion value. This “additive model” is a useful approach as long as there are no such interactions and has been widely used (cf. Vincke, 1992).

Multiplicative models

In many practical situations however, the utilities of some criteria are influenced by other criteria and the simple weighted average approach cannot be used. For instance, the appreciation of visual amenity may depend somewhat on air quality and noise levels. Keeney and Raiffa (1993) developed an approach for such cases based on two assumptions that can reduce considerably this problem of dimensionality. In it the multivariate utility function can be related to the individual utility functions by the

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equation

$$K\,U(X) + 1 = \prod_{i=1}^{n} \{1 + K k_i u_i(x_i)\} \tag{2}$$

where, both $U(X)$ and the $u_i(x_i)$ are scaled so that 0 represents the worst possible situation and 1 the best possible situation.

The multiplicative form of the equation allows a cross influence between consequences. This is best illustrated by expanding the equation for the case of three attributes. This gives

$$\begin{aligned} U(X) = {} & k_1 u_1(x_1) + k_2 u_2(x_2) + k_3 u_3(x_3) + K[k_1 k_2 u_1(x_1) u_2(x_2) + k_1 k_3 u_1(x_1) u_3(x_3) + \\ & k_2 k_3 u_2(x_2) u_3(x_3)] + K^2 k_1 k_2 k_3 u_1(x_1) u_2(x_2) u_3(x_3) \end{aligned} \tag{3}$$

It is readily seen that this includes the simple weighted average as a special case, but also allows for all possible multiplicative combinations of cross influences between attributes.

The individual factors k_i must be determined and they depend on the range of possible values considered for each criterion and should not be interpreted as weights. Together they determine the value of K, i.e.

$$K + 1 = \prod_{i=1}^{n} \{1 + K k_i\} \tag{4}$$

A good introduction to the application of MAUT is given in De Neufville (1990).

4.1.2 Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (Saaty, 1980) is a multi-criteria decision support method that allows qualitative data to be transformed into pair-wise comparison data. It is essentially a formal expression of the decision maker's understanding of a complex problem using a hierarchical structure. It reduces a decision problem to a series of smaller self-contained analyses. The relative merit of each policy alternative is determined from a pair-wise analysis of the relative performance ratings for all combinations of alternatives, separately for each criterion. The relative importance of each criterion can also be determined from a similar pair-wise analysis of decision makers' preferences. The result of the overall process is a ranking of all alternatives on an interval scale. Hierarchies have many advantages. They can be used to describe how changes in priority at upper levels affect priorities of elements in lower levels. They provide detailed information on both the structure and function of the system, they are stable and flexible, and they can mirror reality, since most natural systems are assembled hierarchically.

A hierarchy has at least three levels: the focus or overall goal of the decision problem at the top, multiple criteria in the middle layer, and competing alternatives at the bottom (measures for the WFD). Saaty (1977) suggests using a simple nine point numerical scale, such as the one given in Table 1, to represent the results of each pair-wise comparison. This is supported by psychological studies (Miller, 1956) that show that a scale of about 7 points is sufficiently detailed. Saaty noted that the ability to make qualitative decisions was well represented by five verbal attributes (equality, weak preference, strong preference, very strong preference and absolute preference).

For example, given four elements A, B, C and D within one hierarchy level, each pair – AB, AC, AD, BC, BD, and CD – is directly compared with respect to its influence on X. If, for instance A is mildly preferable to B then the number 3 is placed in the cell at the intersection of the row corresponding to A with the column corresponding to B. Its reciprocal is placed in the symmetrically opposite cell. Inserting all the possible pair-wise comparisons gives a matrix with a structure as in Table 2.

Note that

$$a_{i,j} = \frac{1}{a_{i,j}} \tag{5}$$

The weights can then be determined from this matrix by determining the eigenvector corresponding to its largest eigenvalue, a standard numerical procedure.

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4.1.3 Concordance analysis

Concordance Analysis is a non-compensatory multi-criteria decision support method which indicates the degree of dominance (if any) of any one policy over others (Massam, 1988). The method does not necessarily produce a strict ranking of all the alternatives and some can remain incomparable with some others. For example, if some alternative "a" is better than both "b" and "c", it becomes irrelevant to analyse preferences between b and c and they need not be compared without invalidating the choice of "a". In Concordance Analysis, there is no question of the "trading-off" of one criterion directly against another for each individual alternative. Comparison between alternatives proceeds on a pair-wise basis with respect to each criterion, and establishes the degree of dominance that one alternative has over another. One of the most commonly used methods within Concordance Analysis, the ELECTRE Method, (*Elimination et choix traduisant la réalité*) was originally developed by Benayoun, Roy et al. (1966). ELECTRE involves a systematic analysis of the relationship between all possible pairings of the different alternatives, based on each alternative's scores on a set of common criteria of evaluation. The result is a measure of what is termed the 'outranking' of one alternative over another. While ELECTRE has no axiomatic basis, and incorporates the role of intuition and professional judgement, it nonetheless provides a valuable framework within which to examine multi-criteria problems.

Initially, multi-attribute utility theory (MAUT) was used as it had a strong mathematical axiomatic basis (Keeney and Raiffa 1993). However doubts were expressed about the applicability of its assumptions to the human decision maker or stakeholder. However the effort required establishing utility curves in MAUT does not scale well as the number of criteria increases and the method was difficult to apply to environmental problems with typically large numbers of criteria and mixtures of qualitative and quantitative. The alternative methods described above were developed to cater for these two complicating factors, such as AHP (Saaty, 1980) and ELECTRE (Rogers et al., 1995, 1998).

4.2 Adaptive management

Adaptive management is based on an acceptance that the uncertainties in water resources systems, including its human components, and its external drivers, such as climate change (Pahl-Wostl, 2007a), preclude accurate prediction of the future and thus also preclude attempts at optimal long term policy-making ab initio. A natural alternative is to move into the future in a series of short-term steps each of which includes not only policy formulation but also information gathering to assess the impact of existing policy and help to improve it at the subsequent step (Pahl-Wostl, 2007b). It is, in effect, the "Kalman Filtering" of policy formulation. In such an approach it is logical to devise short-term strategies to test various hypotheses about the response of the entire socio-eco-hydrological system. This is because long-term optimality may be better served by an initial strategy designed to gain information about the system and its response rather than designed only for best initial step towards the goal of "achieving good water status" as soon as possible. However, in practice there may be some resistance to implementing such an approach. In addition, its appropriateness depends on the current state of knowledge about water resources, which varies considerably between EU member states. Sharma and Norton (2005) describe its use in policy formulation in relation to climate change and stress that such methods must take account of how the public response to policy has a role in shaping public attitudes. However, the WFD is structured in a way that allows for adaptive management since its article 13(7) provides for regular review and updating of Water Management Plans on a 6 years cycle.

4.3 Social learning

Tippett et al. (2005) point out that while "it is individuals who learn, they do so in social groups" and thus this knowledge is social. They define social learning as "organisational learning that results in enhancing a group's ability to change its underlying dynamics and assumptions" and point out that this is a requirement for an adequate response to WFD requirements, given the complexity of the systems being managed.

This process is thus a natural adjunct to adaptive management.

4.4 Cognitive mapping

Cognitive mapping (Eden, 1990), which is based on the theory of personal constructs (Kelly, 1955), is a technique to organise, analyse and make sense of descriptions of problems or systems. Cognitive maps are often determined from interviews with stakeholders and they describe how the interviewees represent internally the external environment (Kearney and Kaplan, 1997). It clarifies people's conceptions about their environment by recording them in diagrams showing the concepts and their interconnections. Giordano et al. (2005) applied fuzzy cognitive maps to develop a "water community cognitive map" used in negotiation between stakeholders and for conflict resolution relating to equity in water distribution during drought periods in Italy. Kolkman et al. (2005) pointed out that the complexity of environmental problems and the differences in the conceptualisations of the decision makers, stakeholders and scientists increase the difficulties of negotiation and reaching a consensus. They suggest using a "mental maps" approach to address this and give an example application to the design of the Zwolle storm barrier in the Netherlands. Tan and Ozesmi (2006) used the Fuzzy Cognitive Mapping technique to develop a comprehensive lake ecosystem model from the separate conceptualisations of 8 lake scientists. They found that it not only produced a good model, the exercise produced insights that extended the existing knowledge of the participating experts in a practical way. Tippet et al. (2005) apply cognitive mapping to examine the objectives of forest users.

4.5 Cooperative modelling and design

Giordano et al. (2006) describe cooperation between modellers and the public in developing simulation models to assist in decision making. They question the public participants about their experience of the modelling process and report their opinions on the credibility and value of the resulting model. Dinka and Lundberg (2006) studied the effect of personal identity on cooperation in design teams, noting a distinction between a participant's professional and personal role. Vatn (2007) explores the conditions and reasons for peoples' willingness to cooperate in relation to usage of resources. Regan et al. (2006) describe a mathematical consensus convergence model based on establishing consensus priority weights for individual groups. Shirani (2006) compared the characteristics of face to face discussion within a decision making group with discussion mediated by a Group Support System (GSS). He found that the latter promoted sharing within the group of previously unshared information. Turoff et al. (2002) and Damart et al. (2006) describe how the ELECTRE TRI method can be used to support group decision making. Janssen et al. (2006b) describe the use of simple group decision support tool for land use management in the Netherlands.

5 DSS support

The development of new "soft" techniques and approaches described above required a new set of supporting software tools, some of which are mentioned below.

5.1 For negotiation

Tippett (2004, 2005) points out the challenges of the WFD and describes the "SUNstainable DesignWays" tool and its role in fostering societal participation in forming decisions.

Decisionarium (http://www.decisionarium.hut.fi) (Hamalainen, 2003; Moreno-Jimenez and Polasek, 2003) is a public site for interactive multicriteria decision support with tools for individual choices, group collaboration and negotiation. It includes (a) Web-HIPRE (value tree and AHP analysis); (b) RICH (allows incomplete ordinal preference statements when considering the relative importance of attributes in a value tree); (c) Opinions-Online (a platform for surveys voting and group collaboration) ; (d) Joint Gains (to support multiparty negotiations in a multicriteria setting) and (e) Smart

Swaps (an implementation of the even swaps procedure). All of the tools are web based so global interaction is easy and links can be utilized for multimedia information support.

TED: Towards Electronic Democracy: An e-negotiation system is proposed by the TED project (http://infodoc.escet.urjc.es/ted/), Rubio et al. (2005). It delivers modern methods of decision analysis and group decision support over the internet and makes it easier for the public to participate in decisions that affect them. This makes it easier to obtain, from a wider section of interested parties, the feedback that is essential for the negotiation and compromise phases shown in Fig. 2.

Haseman et al. (2005) describe a Group Decision Support System (GDSS) based on collective memory that uses hypermedia and groupware and intranet facilities. They report that the approach helps participants establish and communicate group norms. This was valuable when the groups were involved in sequences involving similar types of decision making situations. Limayem et al. (2006) consider reasons for some disappointing results. They conclude that although GDSS generally improves the decision making process, when it is not used correctly the results can be worse than for unassisted group decisions. The "e-Participation"' system of Lourenco and Costa (2006) focuses on collaborative writing which can produce consensus building and cooperation between groups or individuals. The intention is that the process would produce agreed documents reflecting different discourses as a useful and acceptable contribution to public decision processes. This is a highly transparent process and the intrinsic value of transparency in promoting the acceptance of the outcome of the decision process has been identified by Kemp et al. (2006), based on their UK experience of involving stakeholders in decisions relating to Best Practical Environmental Alternatives relating to radioactive waste management. They describe a number of different approaches (including fact finding missions, workshops and focus groups) taken in different projects. They emphasize that the decision process should be sufficiently transparent to demonstrate that stakeholders attitudes have been taken into account in arriving at the final decision. An overly complex process can be counter-productive.

Bruce (2006) applies the deductive approach to collaboration and negotiation and suggests seven interesting hypotheses:

- Hypothesis 1. If the parties hold widely divergent views, it is unlikely that they will appear to share common interests. That is, it is unlikely that they will agree concerning the direction of changes to any initial proposals.
- Hypothesis 2. Most negotiations between parties will take the form of "trades". Furthermore, the probability that such trades will take place will not be affected by the degree to which the initial allocation of resources is considered to be undesirable; but will be influenced by the cost of the negotiation process.
- Hypothesis 3. If the policy that the government will select in the absence of collaboration is known to the parties, the outcome they adopt will be strongly influenced by that policy even if the parties reach consensus through open and unfettered bargaining.
- Hypothesis 4. If the parties are uncertain about the policy that will be imposed if they fail to reach agreement (and are risk averse), but share similar perceptions concerning the probabilities that various policies will arise, they will have a greater incentive to reach agreement than if they were certain about the default outcome.
- Hypothesis 5. If the parties have inconsistent expectations concerning the policy that will be imposed if they fail to reach agreement, there is a strong presumption that collaboration will fail.
- Hypothesis 6. If the government "frames" the issues to be negotiated (by restricting the set of possible outcomes), it may increase the probability that the parties will reach consensus. However, it will, at the same time, increase the probability that both parties will be dissatisfied with the outcome they have "chosen".

– Hypothesis 7. The parties' willingness to enter collaborative processes, and their ability to reach mutually beneficial outcomes, will not be affected by the parties' relative economic or political powers (as long as consensus is the decision rule).

He found these hypotheses were supported by the results of a questionnaire survey of people who had participated in a land use management decision making process.

5.2 For compromise

Some systems, called "Stakeholder DSS" have emerged that can be used by decision makers, technical experts and stakeholders to explore the consequences of combining either preference schemes or alternative scenarios in the hope of achieving mutually acceptable compromises. These are often made available and used by stakeholders over the internet. Haemaelaeinen et al. (2001) describe a framework for multicriteria modelling and support for a multi-stakeholder decision processes in relation to water level management in a regulated lake-river system in Finland. The stakeholders are involved in the decision process from formulating problem structuring stage to the group consensus seeking stage followed by a stage of seeking public acceptance for the policy. The framework aims at creating an evolutionary learning process. It also focuses on a new interactive method for finding and identifying Pareto-optimal alternatives. Role playing experiments with students are used to test the practical applicability of a negotiation support procedure called the method of improving directions. It describes the preference programming approach for the aggregation of the stakeholder opinions in the final evaluation of alternatives and consensus seeking.

5.3 For Reflection on priorities

This is an aspect that is rarely addressed in DSS at the moment and has a number of practical difficulties. For instance if a decision support system encourages the changing of objectives as part of the process then can it be used to manipulate the final outcome. The boundary between such manipulation and facilitating the entire process is not clear with potential consequences for the credibility of the system. Of the few publications on the aspect of objectives, Makowski et al. (1997) have produced a system, applied to the Nitra River, in which aspiration-lead objectives can be modified as part of the multi-criteria decision making process.

6 WINCOMS project

To address some of these issues, the WINCOMS project was established. It is a cooperation between hydrologists, sociologists and decision support experts directed at facilitating public participation in decisions relating to policy on "measures" to be adopted within the context of the WFD. Meaningful interaction between numerical modelling and stakeholders is a key goal. The project is funded by the Irish Environmental Protection Agency as part of a response to the objective of including all stakeholders in the decision making process involved in implementing the WFD. The principle objectives are:

- Produce a comprehensive scientific and technical description of all measures available to meet the requirements of the WFD together with a ranking on the basis of all relevant criteria, using formal multi-criteria methods. [⇒ ranked list of measures and criteria]. These results are targeted principally at River Basin District (RBD) decision makers, but will also add to stakeholder and general technical understanding of the performance, advantages and disadvantages of all measures.

- Survey existing decision support systems and identify a short-list of 2 or 3 of the most suitable for WFD decision-making. Implement, adopt and test these in a case-study situation (using the Eastern RBD project), evaluate their performance (particularly in respect of interaction with stakeholders) and recommend the most suitable system or approach. [⇒ survey of DSS, ranked short-list and demonstration of recommended DSS in conjunction with Eastern RBD]. These results will be of wide applicability in environmental decision support. However, their principle targets are stakeholders and decision makers involved in WFD activities.

– Identify and study the knowledge, opinions and preferences of all relevant stakeholders and integrate the results with the decision support systems implemented in objective 2. These results will be of wide applicability in the sociology of environmental opinions and preferences and the communication and influence of science knowledge. However, their principle targets are stakeholders and decision makers involved in WFD activities

As part of the project, a sociology researcher attends (as an observer) all meetings of the Advisory Committee established to oversee the WFD work. Questionnaire surveys establish their concerns and their knowledge and familiarity with computer systems and the internet. After an extensive survey, a number of existing decision support systems have been identified as suitable for use with this group and will be tested as part of the project. These are (i) Decisionarium (Hämäläinen, R.P., 2003) and (ii) certain parts of mDSS4 from the MULINO project (Giupponi et al., 2004). These are currently being assessed for use with the Advisory Committee of the Eastern RBD.

The project will produce state of the art outputs under all three major headings (assessment of measures, evaluation of decision support systems and stakeholder attitudes) and will integrate the knowledge and experience of existing EU-and USA funded projects and the existing work of the RBD Advisory boards and particularly of the Eastern RBD project to provide practical systems or methodologies for socially acceptable and sustainable decision making in the formulation of WFD policies and measures.

7 Conclusions

This paper briefly traces the on-going movement of decision support methodology and the associated computation tools from a position in which they were complex and required specialist users and stand-alone computers to a position in which the complexity is hidden behind easy-to-use Graphical User Interfaces and can be used over the internet. This has being associated with a shift in paradigm from a linear prescriptive process driven by technical and scientific experts to a new iterative, reactive, process given more control to stakeholders. This paper outlines some multi-criteria methods suitable for use with the new paradigm and identified Concordance methods (such as ELECTRE) and the Analytical Hierarchy Process as appropriate tools. This expanded access to and use of decision support systems and related systems analysis methods facilitates public stakeholder participation and is a useful and welcome development and is compatible with the spirit of the WFD. It has provided a framework for new types of research project, such as WINCOMS, which studies how decisions are influenced (or not) by stakeholders increased access to complex tools and sources of information. In the context of the WFD, such projects integrate water science and engineering with sociology in the expectation that the process will lead to more socially acceptable environmental decisions.

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Table 1. Saaty's preference scale.

Preference	index
absolutely preferable	9
strongly preferable	7
preferable	5
mildly preferable	3
equal importance	1

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Table 2. Pair-wise comparison recriprocal matrix for Analytical Hierarchy Process.

	A	B	C	D
A	1	$a_{1,2}$	$a_{1,3}$	$a_{1,4}$
B	$a_{2,1}$	1	$a_{2,3}$	$a_{2,4}$
C	$a_{3,1}$	$a_{3,2}$	1	$a_{3,4}$
D	$a_{4,1}$	$a_{4,2}$	$a_{4,3}$	1

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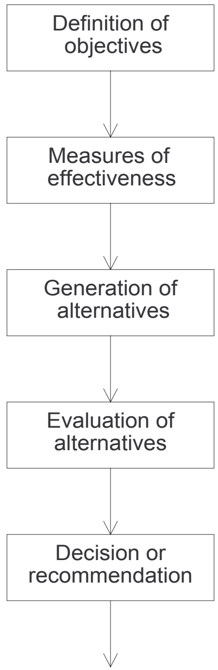

Fig. 1. Systems approach: Classical Paradigm.

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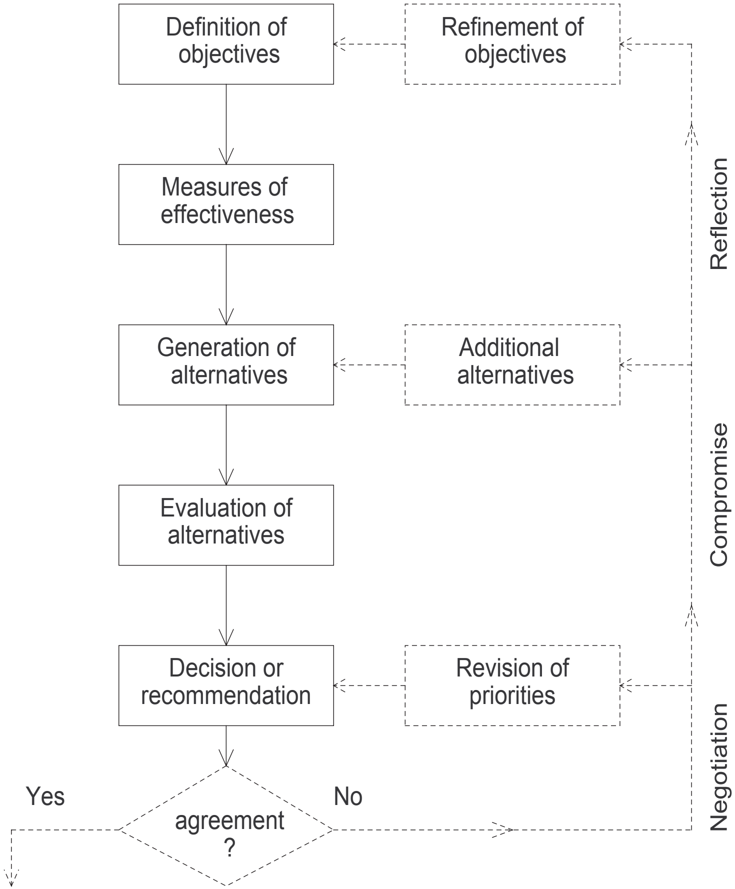

Fig. 2. Systems approach: New Paradigm (Bruen, 2006).

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